3 PRTS

09/807950

PCT/DE 00/03809

532 Rec'd PCT/PTO 20 APR 2001

System for Minimising or Compensating PMD-induced Distortions in Optical Transmission Systems and Transmission Fibres in particular

DESCRIPTION

Field of the invention

The invention relates to a system for minimising or compensating distortions due to polarisation modulation dispersion (**PMD**) in optical transmission systems and transmission fibres in particular.

Prior Art

As any glass fibre is unintentionally birefringent to a slight extent light signals of different polarisations are passed through the glass fibre with different group rates. The light fractions of different polarisations therefore arrive at the receiver with transit times relative to each other; this transit time effect results in a widening of the received signal and hence in an impairment of the quality in transmission. This may lead to an increase of the bit error rate in particular. The useful transmission rate in optical fibre communication networks is hence restricted by PMD-induced distortions. Due to the PMD of the transmission path, which varies in the course of time, high bit error rates and temporary breakdown of the transmission may occur. The existing PMD of the path is a restricting factor especially for the improvement of fibre paths already installed.

The polarisation mode dispersion encompasses all polarisation-dependent transit time effects where the signal propagation can be described completely by the propagating characteristics of two polarisation modes which are independent from each other and orthogonal relative to each other. With birefringence being permanently varied by outside influences such as temperature and mechanical load, and being moreover dependent on the wavelength, both the position of the "principal states of

polarisation" (which will be briefly referred to as **PSP** in the following) and the difference in transit time between the PSPs undergo a permanent variation. This is also referred to as **second-order** polarisation mode dispersion (**PMD**).

A wavelength-dependent PMD behaviour with time constants in the ms range up to the range of minutes results from the aforementioned effects, which fluctuates versus time.

Distortions in transmission systems, which are created by polarisation mode dispersion (PMD), must be compensated for high-rate data transmission applications in order to maintain the signal quality.

Prior Art

The influence of polarisation mode dispersion along long high-rate transmission paths have been intensively studied and measured in the past few years.

In this respect reference is made to the following articles which – like the other articles additionally mentioned in the following, too - are explicitly referred to for explanation of all the particulars not explained here in more details:

- Poole, C.D.; Tkach, R.W.; Chraplyvy, A. R.; Fishman, D.A.:
  Fading in lightwave systems due to polarization-mode dispersion
  IEEE Photoonics Technology Letters, vol. 3, No. 1, 1991, pp. 68 – 70
- Clesca, B; Thiery, J.-P.; Pierre, V.; Havard, V.; Bruyère, F.:
  Impact of polarisation mode dispersion on 10 Gbit/s terrestrial systems over non-dispersion-shifted fibre
  Electronics Letters, vol. 31, NO. 18, 1995, pp. 1594-1596

Moreover, the effects of second-order PMD and also of polarisation-dependent loss (PDL) have been analysed:

- Bruyère, F.:
  Impact of First- and Second-Order PMD in Optical Digital Transmission Systems
  Optical Fiber Technology 2 (1996), Article 33, pp. 269 - 280
- Gisin, N.; Huttner, B.:
  Combined effects of polarization mode dispersion dependent losses in optical

fibers
Optics Communications 142 (1997), pp. 119 – 125

Fairly old fibres in particular, which had been installed in the first years of optical fibre transmission present a high PMD level. For paths to be installed in the future an upper limit of $0.5\ \mathrm{ps}\sqrt{\mathrm{km}}$ applies. Even though the fibre manufacturers take any effort to offer values lower than this maximum, the influence of such comparatively small PMDs is troublesome in the case of high transmission rates and long distances.

The effects of other dispersive phenomena such as chromatic dispersion may be pushed into the background by a suitable selection of the wave length or by means of fibres compensated in terms of dispersion.

The only factor which involves a restriction of the band width and the length of the distance is hence PMD.

On account of the occurrence of PMD, which is invariant in terms of time, compensation is not possible by the use of a constant-PMD fibre. Various simulations have become known - cf. in this respect

- Ozeki, T.; Kudo, T.:
  Adaptive equalization of polarization-mode dispersion
  OFC/IOOC 1993, Technical Digest, pp. 143 - 144

and laboratory experiments - cf. in this context

- Hakki, B. W.:
  Polarization Mode Dispersion Compensation by Phase Diversity Detection
  IEEE Photoonics Technology Letters, vol. 9, No. 1, 1997, pp. 121 - 123

have become known in relation to the wide-band and flexible design of a PMD compensator. These publications, however, refer to laboratory set-ups which are not suitable for application in practice.

From prior art literature various approaches have become known for PMD compensation, with provisions on the receiver side being promising only in view of their implementation. These approaches include:

- the variation of PSP of the fibre path by a polarisation regulator on the receiver side in such a way that the polarisation of the transmitter laser will coincide with a PSP,
- the application of a polarisation diversity receiver with a series-connected polarisation regulator that separates the signals of high-speed and low-speed PSP from each other and joins them again at the output of an electrical time-lag line,
- the application of a birefringent fibre of constant PMD and a series-connected polarisation regulator.

It is moreover known to use a high-speed electronic system for implementation of electronic PMD equalisation and a mechanical adjustable time-lag device for PMD compensation.

The aforementioned proposals are either incomplete because the manner of selective control is not clarified, or they involve a high expenditure in terms of optical and electrical devices, or they do not function properly. Products developed to be marketable have so far not become known worldwide.

One reason for this resides firstly in the aspect that in the past means have not been available for measuring PMD-induced distortions, which are sufficiently rapid and present a sufficiently simple design.

Another reason for this is the fact that an emulator unit has not been available which is capable of emulating the PMD of a real transmission fibre as precisely as possible.

Brief outline of the problem of the invention

Typical demands on a PMD compensator for optical transmission paths are as follows:

- a wide range suitable for compensation: e.g. 0 to 100 ps,
- thorough control down to the lowest possible residual PMD,
- high-speed thorough control in the case of variations along the fibre path,
- reliable control characteristics for any kind of PMD and for PMD with different PSP levels in particular,

- no persistence of control in local minimums,
- low insertion attenuation,
- low variance of the insertion attenuation.

Brief description of the invention

The present invention is based on the problem of providing a system for minimising or compensation PMD-induced distortions in optical transmission systems and in transmission fibres in particular, that permits a high-speed compensation of PMD-induced distortions in a form appropriate for practical application - particularly in view of the afore-defined demands.

Inventive solutions to this problem are defined in the independent Patent Claims. Improvements of these solutions are the subject matters of the dependent Claims.

A system suitable to minimise or compensate PMD-induced distortions must include a means for measuring the PMD-induced distortions. Moreover, (at least) one emulator unit must be provided for adjustable PMD-values, as well as at least one matching element or a polarisation transformer element, respectively, if necessary, which matches the PSPs of the signals leaving a transmission system with the PSPs of the PMD emulator unit.

In accordance with the present invention both the emulator unit and the means for measuring the PMD-induced distortions, as well as the controller and the employed control criterion (alone or in combination) are improved.

In the emulator unit presenting the inventive design an optically operating variable PMD time-lag element is used. This element is preferably composed of two dispersive constant-PMD elements which are connected via a polarisation regulator to a variable PMD element.

By insertion of a variable automatic PMD compensator between the transmission path and the optical receiver an optical compensation of the PMD-induced distortions is successfully achieved so that the bit error rate will be minimised. The transmission

capacity of the path and the maximum distance that can be covered can hence be multiplied by application of this PMD compensator.

In a preferred solution of the invention, which relates to the emulator unit, this emulating unit comprises a PMD emulator which is capable of emulating also the second-order PMD and of emulating the PMD of a real transmission fibre as precisely as possible. The emulator unit of the inventive design presents the particular advantage that a series-connected polarisation transformation element is not required. It is, of course, also possible - even though not necessary - to connect the fibre path to be compensated to the adjustable PMD time-lag element via a further polarisation regulator that operates continuously and causes the principal states of polarization (PSP) of both PMD elements to coincide.

The aforementioned preferred improvement of the invention starts out from a system for compensating distortions induced in optical transmission systems, and transmission fibres in particular, by polarisation modulation dispersion (PMD), which system comprises a means for measuring PMD-induced distortions, an emulator unit for adjustable PMD values and a controller which the output signal of the measuring means is applied to and which controls the emulator unit.

In accordance with the present invention, this emulator unit comprises at least one basic emulator unit composed of two differential group delay elements (DGD elements) having each a defined invariable time-lag period for the incoming signal, which elements are interconnected via a connecting element producing the effect of a transformation element, with all three elements forming a defined angle of the birefringence axes relative to each other.

The birefringence axes of the connecting element are distinguished from the birefringence axes of the two DGD elements in terms of their angular position. Moreover, at least one regulator element is provided for each basic emulator unit, which produces its effects on one of the elements of this basic emulator unit and preferably on the connecting element in such a way that the overall system can be completely ad-

justed by a slight variation of the time-lag generated by the influenced element of the DGD.

The most different elements known from prior art may be used as dispersive elements and specifically as DGD elements, which may be employed in the inventive system.

A multitude of polarisation regulator variants is available for use as polarisation regulators determining the essential parameters of the overall system, such as the response time, the insertion attenuation and the long service life:

- rotatable $\lambda/2$ and $\lambda/4$ wave plates in the free path of the rays,
- fibre squeezers, force produced on highly birefringent fibres,
- lithium niobate or other electrically controllable birefringent crystals,
- magneto-optical YIG crystals,
- nematic or ferroelectric liquid crystals.

The aforementioned elements may be integrated into fibre-optical systems by appropriate fibre coupling systems.

The elements may be PM fibres in particular. In such a case the regulator element may produce mechanical effects on at least one of the DGD elements, expediently the connecting element, for variation of the time-lag interval and hence the polarisation. In particular, the regulator element or elements, which produce a mechanical action, may be fibre squeezers or stretchers with electrically controllable elements such as piezo elements creating a mechanical action on the PM fibre.

The implementation of the different angles of the birefringence axes may be expediently realised by splicing of the individual PM fibres at the desired angle in the case of PM fibres.

It is particularly preferred in such a case that at least one of the regulator elements comprises a ring for distributing the mechanical effect over the longest fibre length possible, on which ring the PM fibre is wound without being twisted. It is moreover expedient that at least one pressurising element creates a pressure on a plurality of

fibre segments of the wound fibre at least at one site. This pressurising element may be an elongating element such as a piezo element or a magnetostrictive element which acts upon at least one segment of a circle that bears against the ring. In such a configuration it is preferable to provide counter-segments relative to at least one part of the circle segments, which bear against the fibre segments and create a pressure on the fibre.

As an alternative and/or additionally to the application of PM fibres it is possible that the elements are birefringent crystals adapted to be electronically influenced in terms of birefringence or that they are one of the other aforementioned elements.

In any case it is preferred that the time-lag interval created by the two DGD elements of each basic emulator unit is equal to and distinctly longer than the delay created by the associated connecting element.

It is furthermore advantageous to select the angles of the birefringence axes of the first DGD elements to be 0° and of the second DGD element to be 90° and that of the connecting element to be 45°, which means a 0°, 45=, 90° system, or alternatively a 0°, 45°, 0° or a 90°, 45°, 0° system, or in any other appropriate manner.

In one embodiment of the invention another element is provided in series at the input side of the two DGD elements and the connecting element for adjusting an optional input PSP level, which may comprise a further birefringent element such as a PM fibre in particular. The angles of the birefringence axes of the series-connected element and the first DGD element are necessarily different from each other. The angular difference corresponds preferably to 45°. In the case of a PM fibre input PSP may be adjusted particularly by creating a mechanical action on the series-connected element or on the series-connected element and the first DGD element.

The series-connected element and/or the connecting element may consist of two PM fibres or two birefringent crystals presenting different angular positions of their birefringence axes, preferably different by 90 ° relative to each other, with the regulator element acting upon one of the two fibres or on one of the crystals in particular.

In order to be able to compensate also higher-order PMD levels it is preferred that at least two systems be connected in tandem for adjustment of a variable DGD, whereof at least one comprises a basic emulator unit, if necessary in combination with a PSP adjusting element. In such a system it is advantageous to provide the individual systems of higher-order PMD compensation in a way that they are composed of basic emulator units including DGD elements providing different time lags.

In accordance with the present invention the measuring means is so configured that for detection of the PMD distortion it detects the polarisation of all spectral fractions contained in the signal output by the emulator unit. To this end the polarisation measuring means may consist of any polarimeter; for example it is possible to employ a system consisting of at least three photodiodes for detecting the Stokes parameters.

Within the scope of the present invention the simplest possible system is preferred which consists, for instance, of a polarizer and an opto-electronic converter such as a photo receiver, that is series-connected to the output side of the polarizer.

As an alternative it is possible that the measuring means includes a polarisation beam splitter with opto-electrical converters such as photo receivers connected to the output terminals of the beam splitter, which output signals are subjected to quotient formation for generating an actual signal for the controller.

Ahead of the polarisation measuring means, a polarisation matching unit may be provided which matches the output polarisation of the emulator unit to that of the polarizer and sets the polarisation for instance in a way that control may aim at a power minimum at the output side of the polarizer.

The polarisation matching unit may be arranged optionally either directly on the polarisation measuring means or directly downstream of the PMD emulator unit and still ahead of the branching coupler leading to the polarisation measuring unit.

The polarisation matching unit may, for instance, comprise two birefringent elements having birefringence axes forming an angle different from 0°, preferably 45°; for ad-

justment of the output polarisation at least one regulator element may be provided which acts upon at least one of the birefringent elements. These elements may be birefringent crystals or PM fibres.

The signal for readjustment of the PMD compensator may be derived from the detected signal of the optical receiver directly via electrical filters. Two different pass characteristics of the filters enable a valuation of the detected signal in terms of occurrence of distortions independently of the signal power. A control algorithm optimises the polarisation elements of the PMD compensator so that the detected signal of the receiver presents the lowest PMD distortions.

It is particularly preferred that a system for distortions induced by polarisation modulation dispersion (PMD) in optical transmission systems and in transmission fibres in particular is so improved that the controller includes several automatic-control loops in which it modulates regulator elements of the emulator unit with different frequencies - in a form resembling the dither technique - such that the controller detects information about the amount and the phase position of the signal output from the emulator unit on the basis of the output signal of the measuring unit, and uses this information for performing a rapid and direct control, and that the controller sets the individual control loops in such a manner that the polarisation will be constant for all spectral fractions contained in the signal.

In such a configuration it is preferred that the controller uses a minimum photo current of the opto-electrical converter(s) as control criterion for setting a constant polarisation for all spectral fractions contained in the signal. In this context the controller is capable of evaluating the output signal of the opto-electrical converter(s) selectively in terms of frequency and phase.

To achieve a particularly high control speed it is expedient that the controller comprises analog control circuits for the regulator elements to which the frequency-selective and phase-selective signals are applied by application of the dither technique.

Moreover, the controller may also control the regulator elements of the polarisation matching unit, particularly with the same control algorithm as that employed for the emulator unit.

It is furthermore possible that the controller comprises a CPU or at least one DSP switching circuit for performing various functions such as for frequency-selective and phase-selective evaluation or for control of the sequence of operations within the system.

In any case, however, the regulated values are set or controlled in a manner that they are defined on the basis of the employed principle of measurement, so that control based on the trial-and-error principle may be omitted.

Due to this inventive configuration it is possible, *inter alia*, to desist from the application of reset algorithms.

It is particularly expedient within the scope of the present invention - also in the sense of an independent solution - to use elements producing a mechanical effect. These elements may be fibre squeezers or stretchers with electrically controllable elements, such as piezo elements, in particular, which produce a mechanical action on the fibre.

When elements producing a mechanical action are employed it is particularly expedient to provide elements having a ring for distribution of the mechanical action over the longest fibre length possible, onto which ring the fibre is wound without being twisted. With this provision, due to the long effective fibre distance, it is possible to operate with comparatively low pressures. Hence fibres may be used which present a standard coating, without a reduction of the service life of the fibre in practical application. In all other cases it would be necessary to use a particularly hard coating so as to avoid a reduction of the service life beyond a reasonable measure.

In another preferred embodiment at least one pressurising element is provided which exerts pressure on a plurality of fibre segments of the wound fibre at least at one site. This pressurising element may be an elongating element in particular, such as a

piezo element that acts upon at least one circle segment of the wound fibres and that bears against the ring. In correspondence with the segments of the circle counter-segments are provided which bear against the fibre segments and exert a pressure on the fibre. This configuration presents the advantage that pressurisation of the fibre is achieved without "stretching" the fibre. It is expedient in this configuration to design it in a way that thermal influence will not be produced on the DGD element.

As the control criterion is preferably derived in an optical manner according to the invention, i.e. not after opto-electronic conversion, the following advantages are achieved in this case:

(a) The PMD compensator system is independent of the bit rate of the data signal (10 GBit or higher).
(b) The PMD compensator system is independent of signal coding (RZ, NRZ, etc.).
(c) The maximum DGD level to be compensated is not limited, as is the case in conventional systems where the limit ranges at 100 ps for 10 Gbit or 25 ps at 40 Gbit, respectively.
(d) Due to the optical signal processing it is possible to employ low-cost opto-electronic converters with a low limiting frequency (in the kHz range rather than in the GHz range as is common in prior art).

Independently of the derivation of the control criterion the following further advantages are achieved:

(a) high-speed compensation
(b) low insertion attenuation
(c) simple and low-cost structure
(d) a rugged structure
(e) trial-and-error control is not required.

When, in accordance with the present invention, the modulation of the regulator elements is performed with different frequencies, the further advantages are also achieved:

(a) a reset algorithm is not necessary

(b) trial-and-error control is not required, and

(c) expensive signal processors are not necessary.

Brief description of the drawing

The invention will now be described in more details by exemplary embodiments with reference to the drawing wherein:

Fig. 1 shows the principle of the structure of a basic emulator unit designed in accordance with the invention;

Fig. 2 illustrates an improvement of the emulator unit shown in Fig. 1;

Fig. 3 illustrates a first embodiment, and

Fig. 4 shows a second embodiment of an inventive system for minimising or compensation of distortions induced by polarisation modulation dispersion (PMD);

Fig. 5 illustrates one example of a rotator used as polarisation regulator;

Fig. 6 shows an example of a polarisation regulator for PSP matching, and

Fig. 7 is a view of an example of a fibre squeezer.

Description of embodiments

Fig. 1 shows the structure of an inventive basic emulator unit. This unit comprises two DGD elements (differential group delay elements) DGD-1 and DGD-2 which present each a defined invariable time lag for the incoming signal, which amounts to 50 ps in the illustrated embodiment, without any restriction of the possible values. The two DGD elements DGD-1 and DGD-2 are interconnected via a connecting element T-DGD having a time lag of 1 ps in the illustrated embodiment.

All three elements present a defined angle of their birefringence axes, with the birefringence axis of the connecting element T-DGD being different in terms of its angular position from the birefringence axes of the two DGD elements DGD-1 and DGD-2.

In the illustrated embodiment the (absolute) angles amount to 0°, 45° (in the initial setting) and 90°.

In the illustrated embodiment moreover a regulator element is provided which is not shown in Fig. 1 and which acts upon the connecting element T-DGD in such a way that the DGD level of the system can be completely set by a slight variation of the time lag of this element.

It is preferable that the elements DGD-1, DGD-2 and T-DGD are PM fibres in the embodiment shown in Fig. 1. The angles may then be set by splicing. The regulator element may create a mechanical action upon at least one of the PM fibres for modifying the time lag and hence the polarisation; for instance it may be a fibre squeezer or stretcher with electrically controllable elements such as piezo elements.

With this arrangement it is possible to set an overall DGD level from 0 ps up to a total of the individual DGD levels (100 ps), to which end merely the DGD level of the transformation element T-DGD by 0.0025 ps is sufficient.

Fig. 2 shows a modification of the embodiment according to Fig. 1 wherein the same elements as those of Fig. 1 are identified by the same reference numerals.

In this embodiment a further element A-DGD is series-connected at the input side of the system consisting of the elements DGD-1, T-DGD and DGD-2, which further element presents an angle of 45° and a time lag of 1 ps in the embodiment shown here. In the illustrated embodiment the time lag of the elements DGD-1 and DGD-2 corresponds to 30 ps in each case, without any restriction of the general applicability.

Moreover, regulators are also provided for the element A-DGD and the element DGD-1. These regulator elements permit the matching of the PSP of the system to the respective application. The regulator element for the transformation element T-DGD serves - like in the embodiment according to Fig. 1 - to set the DGD. In distinction from the system shown in Fig. 1, the system according to Fig. 2 presents the advantage that the dependence of the PSP on the wave length can be compensated.

Fig. 3 illustrates a system for compensating distortions which are induced by polarisation modulation dispersion (PMD) in optical transmission systems and particularly in transmission fibres, wherein two basic emulator units 1 and 2 are employed which are connected in tandem and whereof each presents a structure corresponding to Fig. 2; these two units serve to set the PSP and DGD levels of the signal IN which arrives from the transmission system, for instance a transmission fibre. The signal output from the second basic emulator unit 2 enters a beam splitter 3 that branches off a small fraction of the signal (1 to 5% into a means for measuring PMD-induced distortion.

This measuring means includes a polarisation controller 4 consisting of two fibre segments having each a time lag of 1 ps (in the illustrated embodiment), which segments are connected to each other at an angle of 45°. These two fibre segments are pressurised for setting the polarisation in the manner to be described in the following. The signal output from the second fibre segment enters a polarizer 4' having an amplifier 6 with low-pass effect connected in series at the output side. The output signal of the amplifier 6 serves as input or ACTUAL signal for the controller that is used to set the time lag of the various fibre segments and which will be described in the following.

The controller comprises a phase-sensitive amplifier 7 for each of the regulator elements - which are not illustrated either in Fig. 3 - having a configuration illustrated in the partial view in Fig. 3. Each of the amplifiers 7 presents a comparatively narrow bandwidth of 2 kHz, for example, with the frequency typically ranging between 50 and 90 kHz. The output signal of the phase-sensitive amplifier 7 is applied to the power amplifiers 8 producing an output signal for controlling the regulator elements, which may include piezo elements, for instance, as is shown in Fig. 7 in particular.

The emulator unit presenting the inventive configuration operates as follows:

The PDMC controller is composed of analog automatic-control loops independent of each other, which operate on the principle of modulated regulator elements. The

regulator elements are controlled by an appropriate selection of the frequency (e.g. 50, 55, ... 90 kHz) for the modulation of the individual regulator elements.

The control criterion is the constancy of polarisation for all spectral fractions carried in the signal (DOP = 100 % and polarisation = constant). The polarisation at the input side of the polarizer is so set that a minimum of power will be transmitted. This furnishes a very precise criterion for DOP and SOP. The modulation frequencies arrive at the photo receiver 5 with a corresponding amplitude and phase position and are available for frequency-selective evaluation in correct phase. Hence also the control circuits for the individual regulator elements may be optimised simultaneously and independently of each other.

Fig. 4 shows a second embodiment of an inventive system for minimising or compensating distortions induced in optical transmission systems, and specifically in a transmission fibre IN used as transmission path, which are induced by polarisation modulation dispersion (PMD); this embodiment, too, is based on the fundamental idea to compensate the PMD level of the transmission path by counter-connecting a variable PMD delay element 1. The PMD delay element 1 is connected via a variable polarising regulator 1' to the output of the fibre IN to be compensated. An optical receiver 5 with an amplifier 6 is connected at the output side of the delay element 1, which is followed by a power distributor 51 that distributes the detected data signal 52 from the optical receiver 5 to filters 53 and 54 joined by detectors 55. The output signals 55' and 55" of the detectors 55 are applied to a controller 56 that applies a control algorithm to obtain a control signal which involves a dependence on the degree of distortion of the data signal 52. The control signal is used to readjust the parameters of the variable PMD delay element 1 and the polarisation regulator 1' in such a way that the signal distortion will be reduced to a minimum.

To this end the variable PMD delay element 1 consists of two dispersive elements 11 of the same type, which are connected, for instance, via polarisation regulator 12. Depending on the polarisation transformation, hence the resulting PMD of this PMD delay element 1 can be infinitely set to a value from 0 up to the total of the individual dispersion levels.

As an example, the dispersive elements 11 may be two elements with linear birefringence and consist of highly birefringent fibres (= polarisation-maintaining fibres). The resulting PMD then amounts to:

(PMD 1 + PMD 2) * cos(angle of polarisation rotation).

A simple rotator such as a $\lambda/2$ wave plate or a Faraday rotator is suitable for use as polarisation regulator. As an alternative, the same effect may be achieved by rotating the two dispersive elements relative to each other at the site of their coupling.

Fig. 5 shows an example of a rotator based on a $\lambda/2$ wave plate. The light from the polarisation-maintaining fibre PMF 20 is subjected to collimation by a lens 21, passes through the $\lambda/2$ wave plate, and is then focussed into the PMF output fibre 24 by means of a further lens 23.

The variable polarisation regulator 1 has the function of imaging the two principal states of polarisation (PSP) of the fibre to be compensated onto the PSP of the variable PMD delay element 1 so that the "high-speed" PSP of the fibre will coincide with the "low-speed" PSP of the delay element and the "low-speed PSP" of the fibre will coincide with the "high-speed" PSP of the delay element.

The variable polarisation regulator 1' operates continuously, which means that it does not present any direction in which there is a mechanical or polarisation-optical limitation. For this function it is not sufficient that the polarisation regulator 1' is capable of converting any input polarisation into any output polarisation. The polarisation regulator 1' must therefore have sufficient degrees of freedom in order to be able to ensure a global minimisation of the overall PMD in all cases. When too little degrees of freedom are available there is the risk of control persisting too long in a local PMD minimum, rather than finding the global minimum.

As an example, the variable polarisation regulator 1' according to Fig. 6 may be composed of four $\lambda/4$ wave plates 32 - 35 disposed in tandem, which are freely rotatable. All polarisation transformation operations are infinite, which means that it is possible to realise them without a limit which were complex to circumvent. For cou-

pling the light out of the single-mode input fibre a lens 31 or a fibre collimator is required, and the light is coupled into the output fibre 37 again via a lens 36 after it has passed through the four $\lambda/4$ wave plates 32 - 35.

A control signal reflecting the degree of distortion of the detected data signal 52 is obtained by filtering high-frequency spectral fractions out. To this end the data signal 52 is subdivided by means of the power distributor 51 and supplied to different filters 53 and 54. The basic frequency amounts to 5 GHz, for example, for the transmission of a 10 Gbit/s signal.

This frequency is always present and contributes mainly to the amplitude of the signal. The frequencies responsible for a high edge steepness range at multiples of the basic frequency, i.e. at 10, 15, 20 GHz or at odd-numbered multiples of the basic frequencies.

For instance, two different filters (53 + 54) are employed. Filter 53 is a band-pass filter that selects the basic frequency at 5 GHz whilst filter 54 may be designed as high-pass filter for filtering out frequencies beyond 15 GHz approximately. The two detectors 55 connected on the output side convert the signal amplitudes into two analog signals 55' and 55". The ratio between these two analog values then furnishes, when used as control signal, the degree of distortion of the data signal independently of the signal power. The control algorithm of the controller 56 tends to minimise the control signal, e.g. by performing slight modifications in alternation on all elements taking an influence on the polarisation.

This is possible at a very high rate so that the PMD compensation may be performed in real-time. When the modification results in a reduction of the control signal it persists, or else it is rejected and the next polarisation element is subjected to a variation.

Fig. 7 illustrates a preferred embodiment for an element producing a mechanical effect on a fibre 100 for influencing the polarisation; this element may be a component of the elements A-DGD, T-DGD, DGD or 1' or 12, respectively, for instance. A ring 121 is provided in the housing 121' for distributing the mechanical action on the

longest fibre length possible, onto which ring the fibre is wound without being twisted. What is not represented is the way in which the fibre is introduced into the ring and passed out of the ring or the housing, respectively. The ring 121 consists, for example, of a thin deformable special-steel part. A pressurising element 122, e.g. a piezo element, is disposed in the ring (121), which is supported on two segments 123 of a circle - on one side via an equalising element 122' - which segments in their turn bear against the ring 121. On the side opposite to the circle segments 123 counter-segments 124 are provided which are supported on the housing 121' and bear against the fibre segments so that they pressurise the fibre 100 when the element 122 undergoes a corresponding elongation. Due to the elongation of the piezo element 122 the fibre 100 can hence be selectively subjected to a mechanical load.

Even though the invention has been described in the foregoing by embodiments, without any restriction of the general concept, the most different modifications are conceivable, of course; moreover, it is not only possible to combine the various features of the individual elements in the aforedescribed embodiment with each other, which are claimed as independent inventions in the claims, but it is also possible to combine individual features with embodiments for other elements such as those known from prior art.

The emulator unit provided in correspondence with the invention may, of course, also be employed in other devices which are not envisaged for compensating distortions induced by polarisation modulation dispersion (PMD) in optical transmission systems and transmission fibres, in particularly, but serve merely to generate PMD-induced distortions, e.g. for test applications.